Competency-based Learning in Higher Mathematics Education as a Cluster of Efficient Approaches

Aprendizado Baseado na Competência Aplicado ao Ensino Superior da Matemática como um Cluster de Abordagens Eficientes

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Abstract

This paper presents the research results of what the process of mathematics teaching should be under the competency-based approach allowing to develop a university student's mathematical competency. It indicates that integrative structure of the mathematical competency containing cognitive, practical, motivational and value-based, reflexive and assessment-based components, updates polyparadigm approach in teaching mathematics as an open cluster of approaches; their integrated utilisation under the leading role of competency-based approach contributes to developing all mathematical competency components. It justifies that competency-based, context-based, interdisciplinary, discipline-based and information technology approaches and fundamentalisation play a critical part in polyparadigm approach; the integrated utilisation of all approaches results in synergetic effect. Within this framework the basic principles of competency-based mathematics teaching as well as coherent system to select the contents of mathematics teaching for engineering educational institution students are developed.

Keywords: Mathematical competency. Polyparadigm approach. Didactic basis. Cluster of approaches. System to select the contents of mathematics teaching.

Resumo

Este artigo apresenta resultados de pesquisa sobre como deve ser o processo de ensino da Matemática dentro da abordagem baseada na competência de modo a possibilitar o desenvolvimento das capacidades matemáticas do

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estudante universitário. Os resultados indicam que a estrutura integrante da competência matemática, contemplando os aspectos cognitivo, prático, motivacional, valor intrínseco, reflexivo e avaliativo, confirma a abordagem poliparadigmática do ensino da Matemática como sendo um cluster aberto de abordagens; a utilização integrada dessas abordagens sob a óptica da competência contribui para o desenvolvimento de todos os componentes do domínio da matemática. A pesquisa justifica que as abordagens baseadas em competência, contexto, interdisciplinaridade, organização e tecnologia da informação desempenham um papel fundamental na abordagem poliparadigmática. A utilização integrada de todas as abordagens resulta em um efeito sinergético. Dentro desta estrutura, são desenvolvidos os princípios básicos do ensino da Matemática baseado na competência, assim como um sistema coerente para selecionar conteúdos de ensino para escolas de engenharia.

Palavras-chave: Competência matemática. Abordagem poliparadigmática. Base didática. Cluster de abordagens. Sistema para selecionar conteúdos de ensino.

1 Introduction

Defining the goals and results of modern higher education, the graduate's personal quality system guaranteeing the ability and readiness to making a career is researched as a unity. These personal qualities are integrated with the concept of professional competency that has become the goal and the result of higher education, and competency-based approach is the leading approach to train higher education institution graduates (WARN; TRANTER, 2001; LUNEV, PETROVA; ZARIPOVA, 2013; JOHNSTONE; SOARES, 2014). It appears to be logical to determine the mathematical competency as a projection of the professional competency into the mathematics subject-matter discipline, extracting the graduate's personal qualities formed in mathematics training out of the professional competence.

In the paper we envisage the problem of mathematical competency development. For the purpose we have to answer the following question: what kind of process to train mathematics should be under the competency-based approach to develop students' mathematical competency. Currently the problem has not completely been solved, because the distinctness, what basic principles of mathematics training are to follow under the competency-based approach does not suffice; these principles could allow to develop contents, forms, methods and means of mathematics training, as well as many university disciplines. The problem is determined by the fact that competency-based approach defines the goal and result of education, which is its leading role, but it does not clearly determine coherent contents, forms, methods and means of education (SOBIECHOWSKA; MAISCH, 2006; NOSKOV; SHERSHNEVA 2007; KIRKWOOD; PRICE, 2013; CARRILLO; CONTRERAS; ZAKARYAN, 2014). They should be developed by educators and researchers based on the goal and result of competency-based approach.

The solution of the problem is of importance to realise competency-based approach in practice, especially to develop a methodological framework to teach mathematics, physics,

electrical engineering and other university disciplines contributing to quality increase of higher education. We would like to underline the characteristic aspects of engineer's professional activity connected with complicated equipment and technologies, their fast upgrading, cause the increasing attention to the problem at higher engineering (technical) educational institutions (WILLIAMSON; MARTIN; SCHAUDER, 2003; NOSKOV; SHERSHNEVA, 2007).

The goal of this paper is further development of theoretical foundations for students' mathematics training as future engineers from a perspective of competency-based approach and the development of the foundations of the coherent methodological framework.

To achieve the goal the following problems are solved in the paper: to substantiate the importance of polyparadigm approach (JAKOBSEN; BUCCIARELLI, 2007; YORKE, 2011; HUMPHREY, 2013; WISMATH, 2013) consisting of the integrated utilisation of various approaches in mathematics teaching under the leading role of competency-based approach in the process of developing all mathematical competency components (RAVEN, 1997; RAVEN, 2012); to construct didactic basis of competency-based mathematics teaching; to substantiate the cluster structure of polyparadigm approach; to develop the fundamental teaching principles based on polyparadigm approach allowing to realise competency-based teaching; to develop the coherent system to select the contents for mathematics teaching for engineering educational institution students.

2 The study

The stated problems will be considered in the sections below. We substantiate the importance and appropriateness of polyparadigm approach in mathematics teaching to higher educational institution students as the main methodological approach to develop mathematical competency, and we develop the concept of mathematics teaching to engineering educational institution students based on polyparadigm approach including the complex of basic teaching principles and coherent system to select teaching contents as the main components of methodological system for mathematics teaching.

2.1 Polyparadigm approach as the ground to develop the mathematical competency

Our opinion is that the main aspect of the issue to develop mathematical competency coheres with the professional and mathematical competency structure, where the majority of researchers lays emphasis cognitive, practical, motivational and value-based components as

well as reflexive and assessment-based component (RAVEN, 1984; MACLELLAN, 2008; BATES; O'BRIEN, 2013). We believe developing these components provides for applying various approaches in teaching mathematics.

For instance, fundamentalisation might be considered the main approach for the cognitive component of mathematical competency that is the approach focused on improving the quality of a student's fundamental mathematics training: their basic, core knowledge and knowledge-on-long demand to ensure a graduate's readiness to apply the knowledge to changing professional activity; therefore, fundamentalisation contributes to developing competency (DOERR; CHAMBERS; KEEFER, 2007; SCOTT; MORTIMER; AMETLLER, 2011).

The contextual approach is directly destined to develop practical component of the mathematical competency. The essence of the approach is in modeling professional and social context of student's future job in the process of their training (VERBITSKI, 1991; VERBITSKI, 2006). The contextual approach supplies student's personal involvement into the process of mathematics training, relevance of the training context, ability to apply pedagogical technologies, proposed by other approaches, and the cohesion of training and up-bringing of a professional personality (VERBITSKI, 2006).

Moreover, to develop motivational and value-based component the learner-centered and the contextual approaches are of great importance, they are both directed to develop and support student's relevant emotional sensory state including their cognitive performance (NOSKOV; SHERSHNEVA, 2007; FLEGG; MALLET; LUPTON, 2012).

Finally, reflexive and assessment-based component of the mathematical competency is efficiently developed while using the learner-centered approach, when the significant attention is paid to a student's self-analysis development as well as teaching skill to assess their own cognitive performance and correct the processes (VERBITSKI, 2006).

Therefore, we come to a conclusion that integrative mathematical competency structure predetermines the necessity of comprehensive application of various approaches in teaching, when all competency components are provided; the competency-based approach has got the leading part.

Currently cumulative realization of several paradigms where the leading paradigm plays the dominating part, the other paradigms do not oppose but add to it according to synergetic principle, is considered polyparadigm approach (JAKOBSEN; BUCCIARELLI, 2007; YORKE, 2011; HUMPHREY, 2013; WISMATH, 2013). In relation to this, we proclaim that the polyparadigm approach is comprehensive applying various approaches in teaching mathematics and other university disciplines, such as those relying on different educational paradigms

including the leading competency-based one as well as knowledge-based, learner-centered, system-based and practical competency and others. In this terminology the above conclusion is in the following: integrative competency structure foregrounds the polyparadigm approach as the main methodological approach in higher education as it allows to develop student's all competency components.

We believe this role of polyparadigm approach is based on long-standing assumptions. Therefore, the cardinal tendency to develop approaches for mathematics teaching in Russian technical universities has been the progressive idea generation of multiapproach and polyparadigmality. Indeed, in Russian didactic research on the problems in mathematics teaching at higher engineering educational institutions since the beginning of 1980s, four big directions have been gradually formed; they assume the improvement of the quality of mathematics education on the ground of contextual approach – contextual (professionally oriented) education, interdisciplinary approach – applying interdisciplinary connections of mathematics, discipline-based and information technology approach – applying computing techniques in mathematics training, and fundamentalisation – approach mentioned above. The researchers and educators have proved the efficiency of these approaches regarding many subject domains.

Although in knowledge-based paradigm these approaches, excluding fundamentalisation, were not in great demand or realised, as they were beyond its frame, further due to generating competency-based approach in Russian higher education the idea of multiapproach and polyparadigmality has reinforced. The majority of researchers have realised the contextual, interdisciplinary, discipline-based and information technology approaches and fundametalisation as well as some other approaches have got competency-based background and could be efficiently used to develop mathematical competency. But it should be mentioned though, as before these approaches are applied separately from each other in the process of mathematics teaching.

2.2 Didactic basis of competency-based mathematics teaching

In our opinion admitting appropriateness of complex application of various efficient approaches in mathematics teaching under the leading role of competency-based approach could become the next stage in natural development of the idea of multiapproach and poliparadigmality in higher education. Besides, this stage gives another substantiation of poliparadigm approach as the methodological ground for developing students' mathematical competency.

To select the approaches for mathematics teaching to apply within the poliparadigm approach, we will follow the didactic classification proposed by I. A. Zimnyaya. According to

her opinion, if one considers the teaching approaches "within the main pedagogy categories – the goal, contents, form, method and means of teaching – it is possible to claim, all approaches could exist but mainly regarding to separate categories among the above mentioned" (ZIM-NYAYA, 2006). It could be noted that all pedagogic categories obtain the different didactic commonality and they are presented in the order of its decreasing. The correlation among them and teaching approaches, pointed by I. A. Zimnyaya, allows to classify approaches due to their didactic commonality.

The competency-based approach evidently has the greatest commonality because it determines the goal and the result of mathematics teaching. It is linked with the contents, forms, methods and means of teaching, but it determines them implicitly through description of student's competencies to be developed by the teaching process. The four studied above approaches are the next due to the commonality, as they conform to the teaching contents level and explicitly impact its forming: contextual, interdisciplinary, discipline-based and information technology approaches and fundamentalisation. For example, according to contextual approach the contents of mathematics teaching are filled with the professionally oriented elements.

It is conceived, the didactic commonality of an approach is characterised by its didactic potential, which could be realised in mathematics teaching. Therefore, the approach to form the contents has a great impact on teaching results, than the approaches determining only forms and methods of teaching; the potential of the approach is higher, and it is more efficient than others.

The great didactic potential of contextual, interdisciplinary, discipline-based and information technology approaches and fundamentalisation is determined by the fact, that each of them realises one of the common didactic principles: professional orientation, interdisciplinary links, informatisation and fundamentalisation. These principles are singled out from the amount of common didactic principles by their factual supporting the competency development, being beyond the scope of knowledge-based paradigm of education; they have not been in demand and have not been realised on the right degree. Under the condition of knowledge-based learning these principles used to be common didactic de-jure, but not de-facto.

We believe the essence of transition from knowledge-based mathematics learning to competency-based one is in complete realisation of the stated four principles to achieve the goal and the result of competency-based approach. Therefore, we consider the amount of all the principles of professional orientation, interdisciplinary links, informatisation and fundamentalisation to be the didactic basis of competency-based mathematics education.

It should be noted there are no other approaches able to influence the development of competency-based mathematics learning like this one, as currently there are no other common didactic principles obtaining competency-based background. Hence, within the polyparadigm approach frame it is viable to apply integrated competency-based, contextual, interdisciplinary, discipline-based and information technology approaches and fundamentalisation as approaches obtaining the greatest didactic potential to estimate their efficiency.

Speaking about the issue of possibility for their integrated applying, we consider it to be an issue of their compatibility, consistency of contextual approach and fundamentalisation. However, the problem has been favourably solved, it has been proved under the contextual teaching the quality of fundamental mathematical knowledge is improved (NOSKOV; SHERSHNEVA, 2007).

2.3 Cluster structure of polyparadigm approach

It is at the educator's discretion to include other approaches in mathematics teaching into the polyparadigm approach: they could be of less didactic similarity, though corresponding to form levels, methods and training resources contributing to achieving goals and results of competency-based approach, for example, project-oriented, problem-oriented or task-oriented.

Currently the amount of objects of split-level but having similar purposes is commonly called cluster, hence, it is possible to study the polyparadigm approach as an open consistent cluster of approaches in teaching, and its background is in integrated optimal use of approaches with synergetic effect. The approaches are of various didactic potential: competency-based approach, playing the leading part, as well as the next approaches according to their didactic potential – contextual, interdisciplinary, discipline-based and information technology approaches and fundamentalisation. Cluster openness is understood that an educator can use different approaches within its frame, though with less didactic similarity, but contributing to achieving the goal and results of competency-based approach.

It is important integrated applying these approaches, when they add deficient didactic components to each other, generates synergetic effect. In this vein, competency-based approach is completed with contents, forms, methods and training resources allowing to achieve its goal and results; other approaches, developed within the knowledge-based paradigm, for example, contextual and interdisciplinary, are added with goals and results of competency-based approach coherent to them and improving the results of their usage. For this reason not only a

simple “arithmetic” addition of results of applying teaching approaches occurs, but simultaneous improving the results of each of them – synergetic effect occurs, it reveals in greater non-linear efficiency due to using these approaches.

Thus, we can come to a conclusion the competency-based mathematics learning of technical college and university students could be realised within the cluster of polyparadigm approach.

2.4 Basic principles of competency-based mathematics training

In the view of the above we can consider the main principles of contextual, interdisciplinary, discipline-based and information technology approach and fundamentalisation to be the basic principles of competency-based mathematics training.

The following principles are suggested to be the basic principles of competency-based mathematics training according to polyparadigm approach:

- training should be directed to develop fundamental core knowledge consisting of basic framework invariant knowledge in mathematics as a basement to develop extended competency, that means abilities and readiness to apply the knowledge in the long-term under the conditions of changing professional life (the principle of prolonged competency);
- in the process of training mathematics it is necessary to simulate the professional context of future job of a student (the principle of professional context);
- while training an educator needs to demonstrate the linkage of the learning material to practical issues beyond the scope of mathematics object field regularly that is in every topic (the principle of applied importance);
- in training it should be recommended to use a wide range of mathematics linkage to other related and unrelated disciplines regularly creating situations of interdisciplinary usage of the knowledge in mathematics within the object-field of another discipline (the principle of interdisciplinary integration) (NOSKOV; SHERSHNEVA, 2008; GONÇALVES, PIRES, 2014);
- during the training process it is important to develop regularly the ability and readiness to apply information and communication technologies and knowledge in mathematics in an integrated manner to the professional life (the principle of discipline-based and information technology integration);
- in training and learning mathematics there should be a possibility to evaluate quickly and efficiently the results for both an educator and a student, including constant student’s self-

evaluation by means of the instruments located in the learner-centered educational milieu in the Internet (the principle of quick and efficient reflexivity);

- in training an educator needs to practise sequentially the historically reasonable experience of using the knowledge in mathematics within the process of development of the science field and its applications (the principle of historical continuity).

These principles can become a theoretical fundamental for developing contents, forms, methods and tools of mathematics training to students of engineering university based on the poly-paradigm approach.

3 The system to select the contents of competency-based mathematics training

As a system of mathematics training content selection we propose a three-stage model consisting of the system of the ranked criteria choice, where the didactic requirements to the contents are specified and concretised. The system is presented by a disjunctive-conjunctive formula.

The criteria of the first rank of the selection system are the most important didactic requirements directly linked to realising competency-based, contextual, interdisciplinary approaches as well as discipline-based and information technology approach and fundamentalisation:

- the contents of mathematics teaching should consist of fundamental framework of scientific knowledge contributing to development of student's thematic thinking (the first rank criterion A_1);
- the contents of teaching should include the elements of applied orientation, reflect the main objectives of graduate's professional activity, consider an engineer's system of operation and allow to develop quasiprofessional occupation (criterion A_2);
- the teaching contents should reflect mathematics links to other disciplines, contain the situations of interdisciplinary application of knowledge (criterion A_3);
- the contents should allow to use information and communication technologies in the process of applying knowledge in mathematics to solve educational professionally oriented, interdisciplinary and applied problems while being taught mathematics (criterion A_4).

At the first stage of selecting the basis of mathematics teaching contents is formed by a logical sum, disjunction of the first rank criteria while the contents of education includes the teaching material sufficing at least one of the criteria that will naturally lead to the redundant contents.

Further the contents are necessary to specify and eliminate the redundant components; the result is achieved due to setting an aggregate of selecting criteria of the second rank. These criteria are:

- easy-to-understand criterion – the contents of teaching should be easy to understand by the students (criterion of the second rank B_1);
- the optimal combination criterion of fundamentalisation, professional orientation and interdisciplinary nature in mathematics teaching (criterion B_2);
- learner-centered criterion – under the equal terms it is necessary to prefer the contents having an impact on a student's emotionally sensuous state (criterion B_3);
- prospect criterion – under the equal terms it is essential to include elements of the developing theories into the contents, which will be in demand in the nearest future (criterion B_4).

It is meant that all the second rank criteria need to be applied to the contents developed at the first stage. Therefore, we are referring to the conjunction, intersection of the second rank criteria; that constructs the second stage of the contents.

The final third stage of concretisation and further narrowing the content scope in mathematics teaching is realised with aggregate of the third rank selecting criteria:

- the correspondence criterion of educational information amount to the study time for the discipline (C_1);
- the minimal sufficiency criterion – good contents are not the only we may add something to but not the ones we cannot extract anything without the loss of quality (C_2);
- the minimal complexity criterion – under the equal terms the educational material obtaining the least complexity for both perception and learning is chosen (C_3).

The contents formed at the first and second stages are completed with all criteria of the third rank in the form of their conjunction, intersection, which constructs the third stage of the content selection.

Therefore, the system to select the contents of competency-based mathematics training at the higher engineering educational institutions based on the polyparadigm approach (S) can be presented by the disjunctive-conjunctive formula:

$$S = (A_1 \vee A_2 \vee A_3 \vee A_4) \wedge (B_1 \wedge B_2 \wedge B_3 \wedge B_4) \wedge (C_1 \wedge C_2 \wedge C_3),$$

the formula due to associativity and commutativity of conjunction and disjunction operations correlates with the fact that the second rank and the third rank criteria can be applied successively in any order.

According to the engineering training directions (TOSMUR-BAYAZIT; UBUZ, 2013) an educator can complete the system of content selection with other criteria of the second and the third rank.

Testing the developed mathematics training principles and the corresponding system of the contents selection occurred at Siberian Federal University (SFU) for teaching mathematics to the students – would-be engineers. It demonstrated good results for developing mathematical competency (CARR; BOWE; NI FHLOINN, 2013; FAULKNER; HANNIGAN; FITZMAURICE, 2014).

4 Conclusion

The research has demonstrated the integrative structure of students' mathematical competency, where cognitive, practical, motivational and value-based components as well as reflexive and assessment-based component are the main to focus on, the structure leads to the necessary integrated use of different approaches to mathematics teaching that contributes to developing all mathematical competency components including the approaches based on various educational paradigms; it can be considered to be a polyparadigm approach for mathematics teaching according to the terminology used.

It is revealed the essence of the transition from the knowledge-based mathematics learning to competency-based learning consists of complete realisation of common didactic principles: professional orientation, interdisciplinary links, informatisation and fundamentalisation; the principles were not in demand and were not realised under the knowledge-based learning. The stated common didactic principles can be addressed as the didactic basis of competency-based mathematics learning.

The research of the polyparadigm approach structure in teaching mathematics to students – would-be engineers has shown that it can be considered as open consistent cluster of approaches in training, the essence of that is in integrated, optimal, synergetic effective usage of approaches obtaining different didactic potential: of competency-based one playing the leading part as well as contextual, interdisciplinary, discipline-based and information technology approaches and fundamentalisation – the next approaches according to their didactic potential; they contribute to developing the mathematics teaching contents to estimate their efficiency. Within the cluster the other approaches can be used as the ones defining forms, methods and tools of mathematics training and contributing to achieving the goal and the result of competency-based approach.

On the basis of the main training principles within the contextual, interdisciplinary, discipline-based and information technology approaches and fundamentalisation the basic principles of competency-based training on many university disciplines and disjunction-conjunction system of the content selection are shaped; they were successfully tested for teaching mathematics at SFU.

Thus, competency-based mathematics learning at higher engineering educational institutions can be realized completely within the frame of polyparadigm approach as the described cluster of the efficient approaches.

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